PATENT COOPERATION TREATY

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INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference --	FOR FURTHER ACTION See Form PCT/IPEA/416	
International application No. PCT/DK2004/000611	International filing date *(day/month/year)* 16.09.2004	Priority date *(day/month/year)* 22.09.2003
International Patent Classification (IPC) or national classification and IPC F25B 40/00, F25B 41/06		
Applicant Zimmermann, Lars Christian Wulff		

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 3 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:

   a. ☒ *(sent to the applicant and to the International Bureau)* a total of 7 sheets, as follows:

   ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).

   ☐ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.

   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) __________, containing a sequence listing and/or tables related thereto, in electronic form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

☒	Box No. I	Basis of the report
☐	Box No. II	Priority
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐	Box No. IV	Lack of unity of invention
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐	Box No. VI	Certain documents cited
☐	Box No. VII	Certain defects in the international application
☐	Box No. VIII	Certain observations on the international application

Date of submission of the demand	Date of completion of this report
11.04.2005	18.10.2005
Name and mailing address of the IPEA/SE Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. +46 8 667 72 88	Authorized officer Inger Löfving / JA A Telephone No. +46 8 782 25 00

Box No. I Basis of the report

1. With regard to the language, this report is based on:

☒ the international application in the language in which it was filed

☐ a translation of the international application into ____________, which is the language of a translation furnished for the purposes of:

- ☐ international search (Rules 12.3(a) and 23.1(b))
- ☐ publication of the international application (Rule 12.4(a))
- ☐ international preliminary examination (Rules 55.2(a) and/or 55.3(a))

2. With regard to the elements of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report):*

☐ the international application as originally filed/furnished

☒ the description:

pages __________ as originally filed/furnished
pages* 1-5 received by this Authority on 14.04.2005
pages* __________ received by this Authority on __________

☒ the claims:

pages __________ as originally filed/furnished
pages* __________ as amended (together with any statement) under Article 19
pages* 6 received by this Authority on 14.04.2005
pages* __________ received by this Authority on __________

☒ the drawings:

pages __________ as originally filed/furnished
pages* 1 received by this Authority on 14.04.2005
pages* __________ received by this Authority on __________

☐ a sequence listing and/or any related table(s) – see Supplemental Box Relating to Sequence Listing.

3. ☐ The amendments have resulted in the cancellation of:

- ☐ the description, pages __________
- ☐ the claims, Nos. __________
- ☐ the drawings, sheets/figs __________
- ☐ the sequence listing *(specify)*: __________
- ☐ any table(s) related to the sequence listing *(specify)*: __________

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).

- ☐ the description, pages __________
- ☐ the claims, Nos. __________
- ☐ the drawings, sheets/figs __________
- ☐ the sequence listing *(specify)*: __________
- ☐ any table(s) related to the sequence listing *(specify)*: __________

* *If item 4 applies, some or all of those sheets may be marked "superseded."*

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No.
PCT/DK2004/000611

Box No. V **Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1-2	YES
	Claims		NO
Inventive step (IS)	Claims	1-2	YES
	Claims		NO
Industrial applicability (IA)	Claims	1-2	YES
	Claims		NO

2. Citations and explanations (Rule 70.7)

Document US 2871680 A1, which is considered to represent the most relevant state of the art, discloses a refrigeration circuit with capillary throttling between condenser and receiver, and between receiver and evaporator. There is thermal contact between suction line and receiver orientated that suction gas pass from receiver bottom towards receiver top. There is also contact between suction line and capillary tube connecting condenser and receiver.

The subject-matter of claim 1-2 differs in that there is no need of an extra capillary tube, and that it is a control of the flow.

The subject-matter of claim 1-2 is therefore novel (Article 33(2) PCT).

Accordingly, the invention defined in claims 1-2 is novel and is considered to involve an inventive step. The invention is industrially applicable.

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Circuit with two-step capillary tube throttling and receiver.

This invention relates to a refrigeration circuit as described in the first part of Claim 1. The purpose of such circuit is to control the flow of refrigerant from receiver to evaporator, by the pressure in the receiver, and in such a way that the evaporator is flooded.

Circuits of this kind are known from several patent applications, all with direct flow in the heat exchanger. In consequence of direct flow the outlet temperatures of the two subjects are drawn towards a common temperature, and that means that the heat exchanger cannot cool the receiver down to a temperature close to the evaporator temperature, and that causes the refrigerant to boil in the capillary tube when throttled to the evaporator. Boiling liquid in a capillary tube has a great influence on the mass flow. Figure 3 is a graph illustrating the calculated mass flow through a capillary tube, assuming the refrigerant is at boiling point when entering the capillary tube. The graph illustrates that the mass flow is an increasing function of the pressure drop, for pressure drop less than 5 Kelvin, but almost fixed for pressure drop higher than 5 Kelvin. The graph is calculated for R134a and with evaporator temperature at –20°C, but the tendency is the same for other evaporator temperatures and for other refrigerants such as R404a, R600a and R22. From this basis it follows that the refrigerant flow cannot be controlled directly by the pressure drop, when the pressure drop is higher than 5 Kelvin, but there are several ways to solve the problem, and three of them are presented in the following.

In US250045 the pressure drop between evaporator and receiver is less than 5 Kelvin and thus the pressure drop can be used without problems to control the flow, but the small temperature difference between suction gas and receiver causes two disadvantages. First, the heat exchanger area has to be large, and secondly, even small swing in temperature will result in big swing in mass flow, with the risk of resonance.

In US2871680 the suction line and the receiver form a heat exchanger with direct flow, from bottom to top. The problem with boiling refrigerant in the capillary tube is solved by separating the refrigerant in liquid and flash gas, and then throttling the two components in separate capillary tubes.
The refrigerant enters at the receiver bottom as flash gas. It moves towards the top, exchanging heat with the suction gas, and leaves through a capillary tube at the receiver top. Flash gas only boils slightly doing throttling and the mass flow will be an increasing function of the pressure drop across the capillary tube. Because of the gravitational pull a part of the liquid will fall to the bottom of the receiver, and here it leaves through a separate capillary tube. The liquid boils heavily during throttling and the mass flow will be constant as illustrated on figure 3.
There are two advantages to this solution: the evaporator is flooded and the heat exchanger area may be small. There are two factors reducing the demands for the area: the temperature difference across the heat exchanger is high and much gas leaves the receiver without charging the heat exchanger.
This method causes two disadvantages. First, a extra capillary tube is required, and secondly, the control of the flow is limited, because the liquid flow is constant.

In DK174179 sub-cooling the refrigerant just before it enters the capillary tube solves the problem. The sub-cooling is carried out by means of a separate heat exchanger, which transfers the heat to the evaporator inlet.
With this method there is no problem with boiling refrigerant in the capillary tube regardless of how big the pressure drop is between the evaporator and the receiver. However, one of the main purposes of this circuit is to ensure flooding of the evaporator, and that put a limit on the pressure drop, which may be shown, as follows: The first throttling step, from condenser to receiver, adds heat to the receiver, which increases the temperature and thereby the pressure. The suction gas removes heat from the receiver - thereby decreasing temperature and pressure. The pressure and the temperature in the receiver is forced towards an equilibrium between heat added and heat removed, and at the point of equilibrium, relation **R1** becomes valid:

$$CP_{liquid} * (T_{condenser} - T_{receiver}) = CP_{gas} * (T_{receiver} - T_{evaporator}) + RT * Y \quad \textbf{(R1)}$$

where

CP is the heat capacity of the refrigerant. Index for gas or liquid form.
RT is the heat of evaporation
Y is the rate of refrigerant in liquid form at the outlet from the evaporator.

An essential purpose of the circuit is to keep the evaporator flooded, which implies that Y is positive. This requirement is substituted into **R1** and makes **R2**:

$$R1 \wedge (Y>0) \Rightarrow$$
$$CP_{liquid} * (T_{condensor} - T_{receiver}) > CP_{gas} * (T_{receiver} - T_{evaporator}) \Leftrightarrow$$
$$(T_{receiver} - T_{evaporator}) < (CP_{liquid} / CP_{gas}) * (T_{condensor} - T_{receiver}) \quad \textbf{(R2)}$$

Relation **R2** sets an upper limit on how much of the total pressure drop may be allowed for the second throttling compared to the first throttling, because the pressure drop during the second throttling also establishes the temperature difference across the heat exchanger. It is essential that this pressure drop is as big as possible to ensure that the heat exchanger area is as small as possible.

The invention distinguish from the discussed solutions by having counter current flow in the heat exchanger. The suction gas pass the receiver from the bottom towards the top, and sub-cooling the refrigerant in the bottom of the receiver, whereby the refrigerant is enabled to pass the capillary tube without boiling.
The invention is made up of a pipe shaped receiver and extended with a capillary tube at both ends. Refrigerant is throttled in two steps: first from the condenser to the top of the receiver and subsequently from the bottom of the receiver to the evaporator. The suction line is placed in thermal contact with the pipe shaped receiver - oriented so that the suction gas passes from the bottom towards the top, forming a heat exchanger with counter current flow. The liquid in the bottom of the receiver will be sub-cooled close to the evaporator temperature and the suction gas will be super-heated to close to the receiver temperature. At equilibrium between added and removed heat relation **R3** is valid:

$$CP_{liquid} * (T_{condensor} - T_{evaporator}) = CP_{gas} * (T_{receiver} - T_{evaporator}) + RT * Y \quad \textbf{(R3)}$$

A main purpose of the circuit is to keep the evaporator flooded, which implies that Y is positive. This requirement is substituted into **R3** and makes **R4**:

$$R3 \wedge (Y>0) \Rightarrow$$
$$CP_{liquid} * (T_{condensor} - T_{evaporator}) > CP_{gas} * (T_{receiver} - T_{evaporator}) \Leftrightarrow$$

$$(T_{receiver} - T_{evaporator}) < (CP_{liquid} / CP_{gas}) * (T_{condensor} - T_{evaporator}) \qquad \text{(R4)}$$

The heat capacity of liquid is always higher than the heat capacity of gas. This relation is substituted into **R4** making **R5**:

$$R4 \wedge (CP_{liquid} / CP_{gas}) > 1 \Rightarrow$$
$$(T_{receiver} - T_{evaporator}) < (T_{condensor} - T_{evaporator}) \Leftrightarrow$$
$$T_{receiver} < T_{condensor} \qquad \text{(R5)}$$

Relation **R5** is always true - and the evaporator will be full-flooded without any restrictions on the temperature in the receiver, in contrast to DK174179, which is restricted by **R2**. It, therefore, follows that the temperature in the receiver may be set at a higher temperature and the heat area will be similarly reduced.

Because the liquid is sub-cooled in the bottom of the receiver, it may be throttled directly to the evaporator without any further cooling - but it is important to fulfil the requirement of sub-cooled liquid. The requirement is fulfilled when the evaporator is flooded - because then the evaporator is "bleeding" with liquid refrigerant. Relation **R5** ensures that the evaporator is flooded at equilibrium - so it is a matter of ensuring that the evaporator is flooded before equilibrium. If the evaporator inlet is placed at the evaporator bottom, then most of the refrigerant will be accumulated in the evaporator during standstill - and consequently the evaporator will be flooded at start-up.

Manufactures of small household freezers and refrigerators normally use a capillary tube with thermal contact to the suction line as throttling device, as illustrated in Figure 1. This construction results in superheated suction gas, which yields two advantages: the COP (Coefficient Of Performances) increases (for most refrigerants) and the warm suction gas prevents water from condensing on the suction line, which otherwise might cause damage behind freezers and refrigerators. With the invention the same advantages may be obtained by placing the first capillary tube in thermal contact with the suction line as illustrated on Figure 2 at mark (12).

Description of illustrations:

Figure1 roughly illustrates the circuit normally used for small freezers and refrigerators. The circuit is composed of: compressor (1), condenser (2), liquid line (3), evaporator (4), suction line (5), capillary tube (6), thermal contact between capillary tube and suction line (7).

Figure 2 roughly illustrates the invention, which only differs from Figure 1 by the tube shaped receiver - splitting the capillary tube in two parts.
The invention is made up of: compressor (1), condenser (2), liquid line (3), evaporator (4), suction line (5), capillary tube (8), receiver (9), capillary tube (10), thermal contact between receiver and suction line (11), thermal contact between capillary tube and suction line (12).

Figure 3 illustrates the graph of the calculated mass flow of R134a in a capillary tube. The outlet of the capillary tube is fixed at –20C and the inlet temperature is varying from –20C to +25C. On entering the refrigerant is at boiling point.

Implementation of the invention:
The invention is composed of 4 parts, a suction line, a pipe shaped receiver and 2 pieces of capillary tubes. As an example suitable dimensions are calculated for a 100Watt freezer with Danfoss compressor NLY9KK. The temperature in the receiver has been chosen to +10C.
From NLY9KK data sheet:

- Refrigerant: R600A
- Cooling effect at 30C/-30C (condenser/evaporator) 100W
- Mass flow: 1.37kg/h = 0.34g/s

Heat is transferred to the suction line at three locations:

1. From capillary tube:
   $Q_{capillary} = Flow * CP_{gas} * 20K = 0.34g/s * 1.7J/g/K * 20K = 12W$
2. From condensing of gas in top of the receiver:
   $Q_{gas} = Flow \times CP_{liquid} \times 20K - Q_{capillary}$
   $= 0.34g/s * 2.3J/g/K * 20K - 12W = 16W - 12W = 4W$
3. From sub-cooling of liquid at the bottom of the receiver
   $Q_{liquid} = Flow * CP_{liquid} * 40K = 0.34g/s * 2.3J/g/K * 40K = 31W$

A heat exchanger is capable of transferring this quantity of heat:

$$Q = U * A * LMTD \qquad (R6)$$

where

U : heat transfer coefficient
A: heat transfer area
LMTD: Logarithmic Mean Temperature Difference

For a tube heat exchanger like this:

$U = 0.1W/cm^2/K$

$LMTD = (dT_1 - dT_2) / LN(dT_1 / dT_2)$

where

dT_1 and dT_2 are the temperature difference at the heat exchanger inlet and outlet. For simplicity the temperature difference at the heat exchanger outlet is here chosen as:

$dT_2 = 1K$

The bottleneck of the heat transfer is the inside area of the suction line, and the minimum of this area is calculated from a rearrangement of R6 into R7;

$Q = U * A * LMTD \Leftrightarrow$

$$A = Q/(U * LMTD) \qquad (R7)$$

By substitution into R7, the minimum thermal contact areas are calculated for the three locations on the suction line:

1. Along the capillary tube, se Figure 2 mark 12:
   $dT_1 = [\,20K * (1 - CP_{gas}/ CP_{liquid})\,] = 5.5K \wedge (dT_2 = 1K) \Rightarrow$
   $LMTD = (dT_1 - dT_2) / LN(dT_1 / dT_2) = 4.5K/LN(5.5) = 2.6K$
   $A_{capillary} >= Q_{capillary}/(U * LMTD) = 12W/(0.1W/cm^2 /K \times 2.6K) = 46cm^2$
   The length of the capillary tube heat exchanger has to be no less than:
   $L_{capillarry} > 46cm^2 / 1.5cm = 31cm$

2. Condensing at the receiver top:
   $(dT2 = 40K) \wedge (dT2 = 1K) \Rightarrow$
   $LMTD = (dT_1 - dT_2) / LN(dT_1 / dT_2) = 39 / LN(40) = 10.6K$
   $A_{condensing} >= Q_{condensing} / (U * LMTD) = 4W/(0.1W/cm^2/K * 10.6K) = 4cm^2$
   Hence it follows that the suction line contact with receiver top must be no less than:
   $L_{Receiver\ top} > 4cm^2 / 1.5cm = 3cm$
3. For sub-cooling at the receiver bottom
   $(dT_1 = 40K) \wedge (dT2 = 1K) \Rightarrow$
   $LMTD = (dT_1 - dT_2) / LN(dT_1 / dT_2) = 39 / LN(40) = 10.6K$
   $A_{condensing} >= Q_{condensing} / (U * LMTD) = 31W/(0.1W/cm^2/K * 11K) = 28cm^2$
   and thus the suction line contact with receiver bottom must be no less than:
   $L_{Receiver\ bottom} > 28cm^2 /(150cm^2/m) = 19cm$

The calculations show:
1. The thermal contact between capillary tube and suction line must be no less than 31cm.
2. The contact between receiver and suction line must extend no less than (3cm + 19cm =) 22cm.

When choosing a receiver of 50 cm length the level of refrigerant may vary by 28cm - and still comply with the basic requirement: that at least 22 cm is available for heat transfer. When choosing the receiver diameter 22 mm the volume of refrigerant may vary with 75 ml corresponding to 45g of refrigerant. The part list will be as follows: Please refer Figure 2:
- Suction line: 6 mm x 120 cm copper tube (5,11,12)
- Receiver: 22 mm x 50 cm (9)
- First throttling: 0,7 mm x 90 cm capillary tube with no less than 31cm thermal contact to suction line (12)
- Second throttling: 0,7 mm x 90 cm capillary tube (10)

The invention provides an effective and cheap regulator as an alternative to the traditional capillary tube throttling for small household freezers and refrigerators. The regulator makes freezers and refrigerators more effective in operation and better suited for varying temperatures. It is simple for manufacturers to adapt the invention - a look at Figures 1 and 2 shows that the only difference is a small receiver placed at the middle of the capillary tube.

Claims:

Claim 1: A closed refrigeration circuit comprising compressor (1), condenser (2), evaporator (4), receiver (9), and with capillary throttling (8) between condenser and receiver and with capillary throttling (10) between receiver and evaporator and thermal contact (11) between suction line and receiver characterized by the refrigerant in the receiver flows from the top towards the bottom and the suction line is oriented so that the suction gas passes the receiver from receiver bottom towards receiver top.

Claim 2: A closed refrigeration circuit as claimed in Claim 1 characterized by thermal contact (12) between suction line and the capillary tube (8) connecting condenser and receiver.

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Figure 1

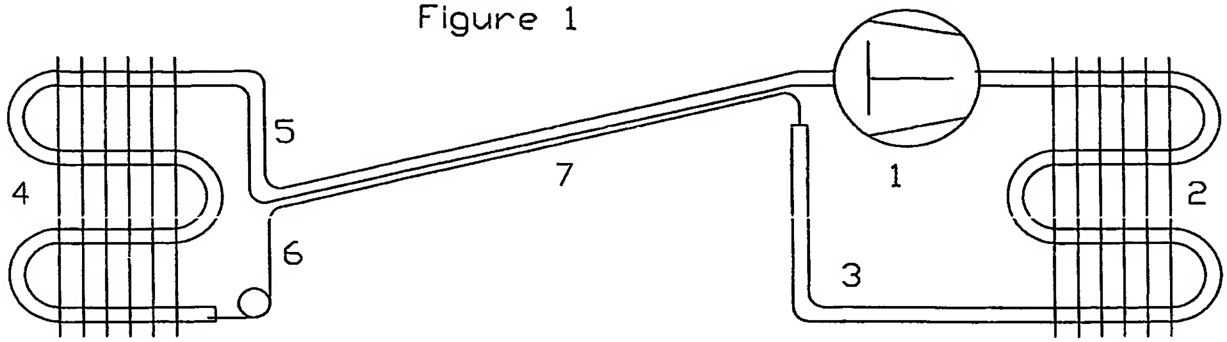

Figure 2